MSD-50-TR-2002/15 Structural Analysis of Alvin Variable Ballast Piping

Anteon corporation

Machinery Systems Group

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TECHNICAL REPORT

Structural Analysis of Alvin Variable Ballast Piping

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A constructual analysis of the Alvin variable ballast system was conducted in accordance with NAVSEA SS800-SG-MAN-010/P-9290 Rev. A (9290). This analysis evaluated all the stress cataegories listed in 9290 Section B.10.2. A fatique analysis in accordance with ASME Boiler and Pressure Vessel Code, Section III, Division 1, consistant with the structural design basis of 9290 Section B.10.2., was also performed.

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N00014-02-1-0108

Structural Analysis of Alvin VB Piping

For the period:
October 22, 2001 – January 31, 2002

As a result of *Alvin's* post overhaul NAVSEA survey an analysis of newly installed variable ballast system piping was required to determine if the piping met the requirements of NAVSEA P-9290. Anteon Corporation was contracted to do the analysis and completed the project in January 2002. The analyses concluded that all stresses were below their applicable allowable values. The fatigue analysis established a design fatigue life of 30,000 cycles. Based on average usage this would provide a design life of 200 years for the new variable ballast piping. The Anteon report was submitted to NAVSEA, reviewed and accepted.

Abstract

A structural analysis of the Alvin variable ballast system was conducted in accordance with NAVSEA SS800-AG-MAN-010/P-9290 Rev. A (9290). The analysis determined stresses for all stress categories listed in Section B10.2.1 of 9290. Fatigue analysis performed in accordance with the ASME Boiler and Pressure Vessel Code, Section III, Division 1, which is consistent with the structural design basis of Section B.10.2 of 9290, established a design fatigue life of 30,000 cycles. Based on an average of 150 cycles per year, the design life for fatigue of the variable ballast system is 200 years.

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Administrative Information

This study was performed under Purchase Order No. S108770. The work was sponsored by the Woods Hole Oceanographic Institution, Woods Hole, MA (Mr. Robert Brown). The work described in this report was performed at the Anteon Corporation, Machinery Systems Group facility in Annapolis, MD.

Introduction

The Machinery Systems Group of Anteon Corporation was tasked by Woods Hole Oceanographic Institution to conduct a fatigue analysis of the variable ballast system on the submersible Alvin.

Background

Chronic problems with the sealing of mechanical joints in the variable ballast piping on the submersible Alvin occurred due to the high strength of the original 3Al-2.5V-Titanium tubing. Based on recommendations from the fitting supplier the tubing material was changed to Grade 2 Titanium tubing in accordance ASTM B338. Since the Grade 2 Titanium is weaker than 3Al-2.5V-Titanium, a structural analysis is required to verify the structural adequacy of the weaker material.

Approach

The structural design basis for deep submersibles is established by NAVSEA SS800-AG-MAN-010/P-9290 Rev. A (9290)[1]. This design basis provides for the following categories of stress:

- Primary stress. A primary stress is one, which is required to produce a state of equilibrium with the applied loads. Primary stresses are not self-limiting. Internal pressure and weight are two examples of loads causing primary stresses. Primary stresses are further classified as general membrane stress, local membrane stress and bending stress.
- Secondary stress. A stress developed by constraint of adjacent parts of the component and not required to produce equilibrium with applied loads. Secondary stresses are self-limiting. Submergence anchor movements, for example, cause secondary stresses in piping.
- Peak stress. The maximum combined stress at any point. The peak stress will be the maximum combined primary and secondary stresses suitably intensified for local stress concentrations. Peak stresses typically do not cause noticeable distortion and are primarily a concern for fatigue life or brittle fracture.

Specific limits on stresses of these categories are provided in 9290 as multiples of the allowable operating stress, S_m. For nonferrous materials, S_m is defined in 9290 as the lesser of two-thirds of the minimum yield strength or one-forth of the minimum specified tensile strength. The stresses and their limiting value are listed below. Of the stresses listed, the first three are primary stresses, and the fourth is the summation of primary plus secondary stresses.

- General membrane stress should not exceed S_m.
- Local membrane stress must not exceed 1.5 S_m.
- The highest value of the combination of membrane stress and primary bending stress must not exceed 1.5 S_m.
- The highest valued combination of primary and secondary stresses must not exceed 3 S_m.
- Peak stresses, including the effects of local stress concentrations, must be limited by fatigue considerations.

Calculation of the above listed stresses requires the use of stress intensification factors. However, 9290 does not provide guidance for establishing stress intensification factors for piping except in section B.2.1, which states: "Stress concentration factors used in the calculation of peak stresses shall be based on experimental data on similar structures." Obviously experiments to determine stress intensification factors are beyond the scope of this task. Therefore, existing recognized methodology must be used. Methodologies closely resembling that of 9290 are provided in the ASME Boiler and Pressure Vessel (B&PV) Code Section III, and ASME B&PV Code Section VIII, Division 2. Of the two, ASME B&PV Code Section III is the most suitable for the analysis of piping and is used for the analysis of the Alvin variable ballast system.

The theoretical basis of the ASME B&PV Code Section III methodology is described in "Criteria of the ASME Boiler and Pressure Vessel Code for Design by Analysis in Section III and VIII, Division 2"[2], hereafter referred to as the "ASME Criteria". The ASME Criteria lists the stress categories that are evaluated as primary stress, secondary stress and peak stress. Table 1 of the ASME Criteria lists the stress limits as multiples of the design stress intensity values, S_m. The multiples in the ASME Criteria are identical to the multiples used in 9290. The ASME S_m values differ from 9290 in that one-third of the minimum specified tensile strength is used for nonferrous materials instead of the one-forth as required by 9290. The Alvin variable ballast system analysis uses the 9290 S_m values.

The fatigue analysis described in the ASME Criteria is consistent with 9290 requirements. However, design fatigue curves for Grade 2 Titanium developed by Czyryca[3] are used in the Alvin variable ballast system fatigue analysis because the ASME code does not have fatigue curves for Titanium. Czyryca's curves are consistent with the ASME Criteria, and the correction for hold time included in the curves is considered necessary to account for Grade 2 Titanium's susceptibility to creep and stress relaxation at room temperature. Stress indices used in the ASME Section III analyses have been verified by experimental testing as required in 9290. Although numerous investigators have conducted experimental verification, the paper by Rodabaugh and Moore[4] is cited as an example of experimental verification for girth butt welds, butt welding elbows, tees, and girth fillet welds. Unfortunately, the Alvin variable ballast system is fabricated using clamped connections, which are not addressed in ASME Section III. However, Markl[5] showed clamp connection on Carbon steel piping have the same fatigue resistance as girth butt welds. Therefore, stress indices for girth butt welds are used in the Alvin variable ballast system analyses.

External pressure loads are evaluated separately from the primary loads discussed above. Two methods are used. One is contained in ASME B&PV Code Section III NB-3133.3, and the other is work conducted by Kaldor[6]. The SUBSAFE Design Review Procedures Manual[7] invokes Kaldor's work for SUBSAFE piping on operational submarines with the caveat that the design pressure to be used is the design pressure established by Kaldor, divided by 1.5. The factors of safety on collapse of the two methods are roughly 3 for the ASME method and 1.5 for the SUBSAFE method.

Structural Adequacy Calculations

Structural adequacy calculations are performed using loads calculated by piping flexibility analysis. Although 9290 does not require flexibility analysis of ½-inch diameter tubing, it does require the tubing to be arranged such that the relative deflections of anchors and restraints do not cause excessive stresses. Because the piping run connecting to the bottom of the two lower spheres of the Alvin variable ballast system appears relatively stiff, flexibility analysis calculations are performed to verify the acceptability of the stresses of the complete system.

Review Information

The following information is provided, in accordance with 9290, to permit easy review of the calculations.

- Theoretical basis of calculations – The theoretical basis of calculations is the ASME Criteria[2], which is consistent with 9290 and is addressed at length in the above approach discussion.
- Method of performing calculations – Flexibility analysis calculations are performed using the AUTOPIPE computer program, a NAVSEA approved program. Flexibility factors in accordance with ASME B31.1 are used as required by Section B.10.1 of 9290. Moments thus calculated are used to calculate stresses for all required categories of stresses using the methodology of ASME B&PV Section III.
- Sign Convention – The sign convention has the X-axis forward, the Y-axis vertically upward, and the Z-axis to starboard.
- Simplifying assumptions – The following simplifying assumptions were used:
    - All temperature changes are gradual and represent uniform thermal expansion.
    - No differential thermal expansion exists between the frame, piping and pressure spheres because the frame, piping and pressure spheres. All of the stated items are fabricated from Titanium, have the same coefficient of thermal expansion, have no sources of heating or cooling, and are fully immersed in seawater.

- Assumed material and dimensional Data – The variable ballast tubing is in accordance with ASTM B338 and is Grade 2 Titanium with an outside diameter of 0.5 inches and a nominal wall thickness of .065 inches. Although ASTM B338 allows a ± 10% variation in wall thickness, nominal wall thickness is used for calculation of all stress categories except general membrane stress.
- Fatigue reduction factors – No stress reduction factors are used because the ASME B&PV Section III methodology uses fatigue curves for the actual material rather than general fatigue reduction factors that are applied to all materials. A fatigue curve for Grade 2 titanium developed by Czyryca[3] that includes the effects of creep and stress relaxation at room temperature is used. Consistent with the ASME Criteria, the fatigue curve is corrected for the maximum effect of mean stress.
- Stress intensification factors – Stress indices from the ASME B&PV Code Section III are used. Indices for a girth butt welds are used for the Swagelok connections because no stress indices exist for Swagelok connections. Testing has shown clamped connections have similar fatigue strength to girth butt welds. The Code equation for C_2 for girth butt welds in pipes with wall thickness less than 0.237 inches is:

$$C_2 = 1.0 + \frac{0.094}{t}$$

As noted by Rodabaugh[8], the purpose of the 0.094/t-term is to correct for weld reinforcement and mismatch. The correction term may be neglected in the Alvin variable ballast system analysis for the following two reasons.

  - Markl[5] used pipe with 0.237 inches thickness to show that the fatigue strength of a clamped connection equivalent to a girth butt weld. Test data for pipe with 0.237 inches thickness would only have a minor influence due to weld reinforcement and mismatch.
  - Swagelok connections have no weld reinforcement and mismatch.

Stress indices used in the Alvin variable ballast system analysis are tabulated below.

Table 1. Stress Indices

	Pressure Loading			Moment loading		
Piping Product or Joint	B_1	C_1	K_1	B_2	C_2	K_2
Straight pipe remote from discontinuities	0.5	1.0	1.0	1.0	1.0	1.0
Swagelok terminations	0.5	1.0	1.2	1.5	1.0	1.8
Bends	0.5	1.06	1.0	1.0	1.5	1.0

- Allowable stress range – The allowable operating stress, S_m, for nonferrous materials, are the lesser of two-thirds of the minimum yield strength or one-forth of the minimum specified tensile strength. For the minimum yield strength of 40

ksi and minimum specified tensile strength of 50 ksi listed in ASTM B338, the design stress intensity value is 12,500 psi. Limits on stresses of the various categories are shown below.

- General membrane stress should not exceed 12,500 psi.
- Local membrane stress must not exceed 18,750 psi.
- The highest value of the combination of membrane stress and primary bending stress must not exceed 18,750 psi.
- The highest valued combination of primary and secondary stresses must not exceed 37,500 psi.

- Deflection of anchors and support points – Anchor movements for temperature change are zero, based on the assumption that no differential thermal expansion exists between the frame, piping and pressure spheres. However, submergence pressure results in deformation of the variable ballast spheres. Deformation of the four upper spheres does not cause piping anchor deflections because the upper spheres are mounted to the frame at the piping attachment point, only. However, deformation of the two lower spheres does result in anchor deflections. Deformations were calculated by assuming the spheres to be of uniform thickness. Appendix 1 contains the calculations. The uniform thickness assumption is valid except for thickening at the piping connections, which is deemed to have a minimal effect on deformations. Deformations of the spheres are applied to an AUTOPIPE beam model of the supporting brackets shown in figure 1. The sphere is included as a stiff pipe with thermal expansion equal to the sphere's pressure deformation. Only the starboard sphere and the starboard half of the supporting brackets are modeled. The port half is replaced by symmetric boundary conditions at the centerline. Except of the reflected port side, the remainder of the frame, not included in the model, is considered as rigid. Appendix 2 provides the output of the AUTOPIPE analysis.

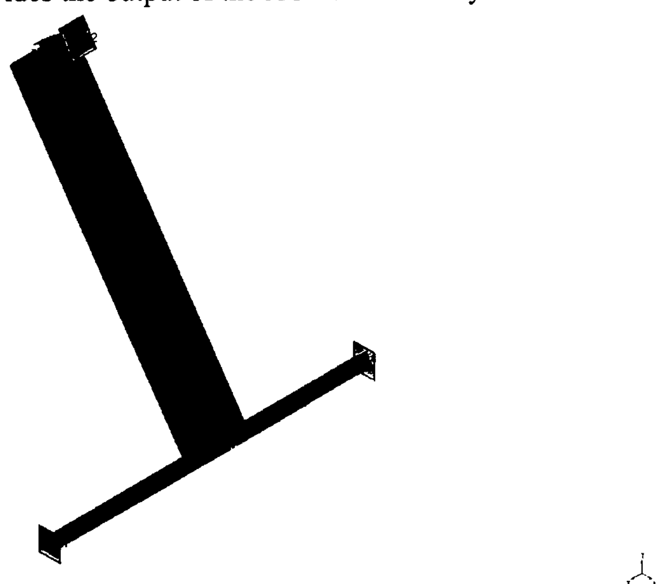

Figure 1. Beam Model of Pressure Lower Sphere Mounting Brackets

Piping Flexibility Analysis

Piping flexibility analysis models were prepared for the upper and lower piping sections of the variable ballast system. Figures 2 and 3 show the idealizations, which were used to calculate responses due to weight and submergence anchor deflections.

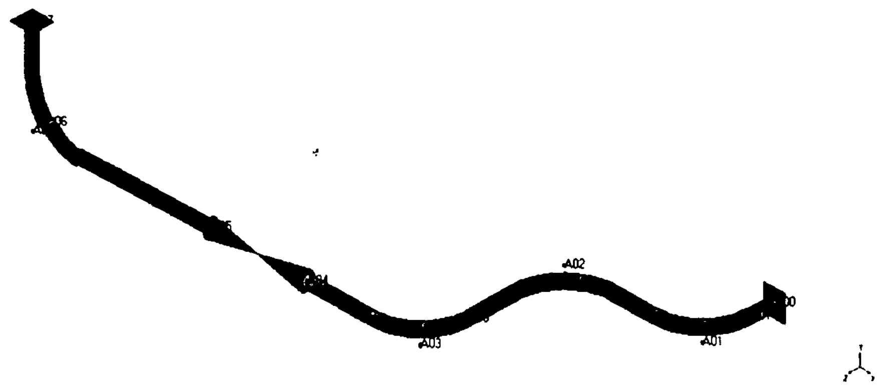

Figure 2. Lower Piping Flexibility Analysis Model

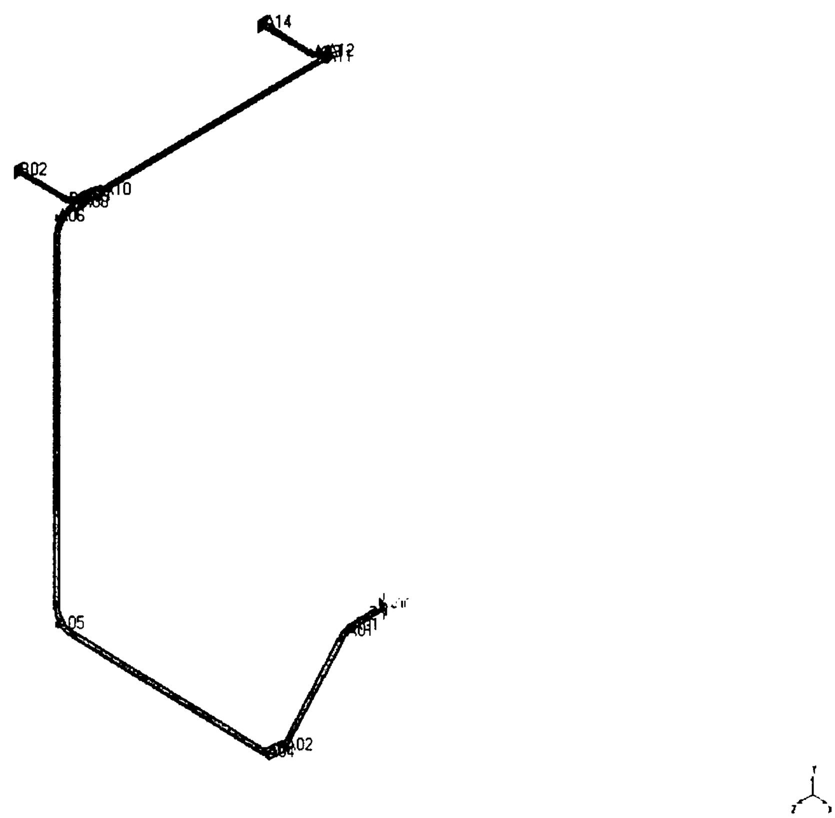

Figure 3. Upper Piping Flexibility Analysis Model

Although no dynamic motion criteria were provided for Alvin, responses were calculated for 30° pitch and roll for completeness. The pitch and roll responses were calculated by rotating each of the above two models to the various pitch and roll orientations. Although this method neglects dynamic loads, dynamic loads are small and typically are not considered in pitch and roll analyses of operational submarine piping. Each of the various orientations was evaluated both above water and submerged. Buoyancy was included in all submergence cases. For the upper run only, the pipe was considered as empty in all submergence cases. Table 2, below, tabulates the load conditions analyzed.

Table 2. Analyzed Loads

Loading	Ship Attitude
Submergence anchor deformations	N/A
Weight	Even keel
Weight	30° Pitch up
Weight	30° Pitch down
Weight	30° Roll port
Weight	30° Roll starboard
Weight plus buoyancy	Even keel
Weight plus buoyancy	30° Pitch up
Weight plus buoyancy	30° Pitch down
Weight plus buoyancy	30° Roll port
Weight plus buoyancy	30° Roll starboard

Appendices 3 and 4 provide listings of the AUTOPIPE output for submergence anchor movements and above water, even keel gravity loads. The appendices include listings of B31.1 stresses for information, however; only the calculated moments are used for the structural adequacy evaluation. Appendix 5 lists the calculated primary bending moments for the most highly loaded straight pipe and the most highly loaded bend. Load ranges were determined for all possible combinations of the analyzed loads and the worst-case resultant moments used in the structural adequacy evaluation. Appendix 6 shows the primary plus secondary bending moment ranges for the most highly loaded straight pipe and the most highly loaded bend.

Results

Structural adequacy calculations are included in Appendix 7 and are summarized in Table 3. The moments used in the calculations are the maximum for all load combinations. Since no cyclic design history exists, cumulative damage calculations are not provided, and pitch and roll loads are combined with submergence loads where they have the most impact on fatigue life. The impact of pitch and roll loads taken separately is insignificant. The largest peak stress for pitch or roll load cycles is only 810 psi compared to 42,881 psi for submergence only.

Table 3. Calculated Stresses

Stress Category	Calculated Stress	Limiting Value
General membrane stress	10274 psi	12,500 psi
Local membrane stress	10274 psi	18,750 psi
Membrane stress plus primary bending stress	6495 psi	18,750 psi
Primary plus secondary stresses	36526 psi	37,500 psi
Peak stress	43047 psi	N/A

The tabulated value for the primary plus secondary stress is 97% of the allowable value. The high value validates the need for conducting the flexibility analysis. The calculated peak stress is divided by 2 to obtain the stress amplitude, and the stress amplitude is entered on the ordinate of Czyryca's fatigue curve[3], reproduced below. Reading from the lower curve, the design fatigue life is 30,000 cycles.

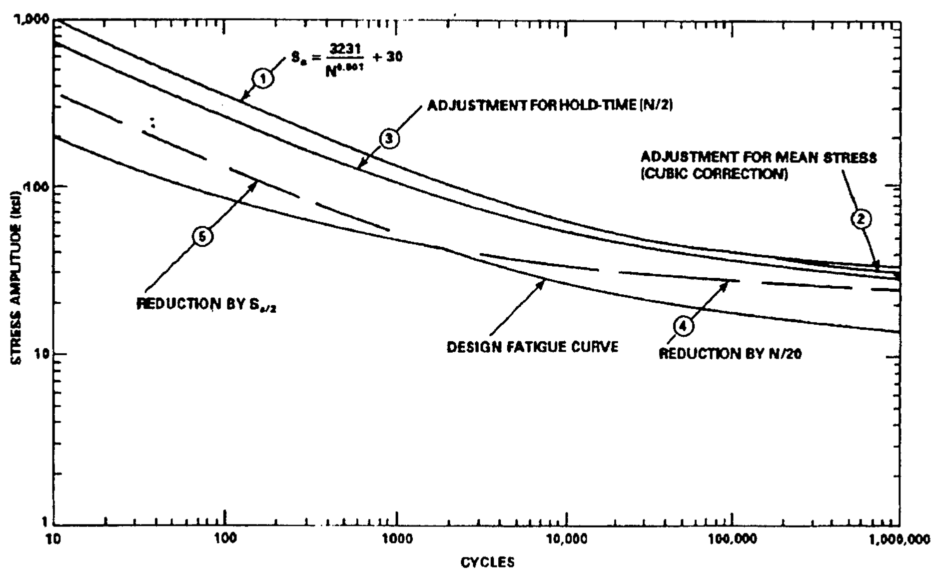

Figure 4. Fatigue Curve for Grade 2 Titanium Including Effect of Hold Time

External pressure calculations are included in Appendix 8 and show the variable ballast tubing to fail the ASME method but pass the SUBSAFE method. The disparity stems from the factors of safety included in the calculations. The factor of safety on collapse for the ASME method is roughly 3 and 1.5 for the SUBSAFE method. Since the tubing passes the SUBSAFE method, which is used for operational submarines, and since samples of the tubing have been tested for external pressure, its external pressure performance is considered satisfactory.

Conclusions

The analyses described herein determined stresses for all stress categories listed in Section B10.2.1 of 9290. All stresses were below their applicable allowable values. Fatigue analysis performed in accordance with the ASME Boiler and Pressure Vessel Code, Section III, Division 1, which is consistent with the structural design basis of Section B.10.2 of 9290, established a design fatigue life of 30,000 cycles. Based on an average of 150 cycles per year, the design life of the Titanium tube in the variable ballast system is 200 years.

References

1. System Certification Procedures and Criteria Manual for Deep Submergence Systems, NAVSEA SS800-AG-MAN-010/P-9290, Rev. A

2. "Criteria of the ASME Boiler and Pressure Vessel Code for Design by Analysis in Section III and VIII, Division 2", ASME

3. Czyryca, E.J., "The Effect of Hold-Time on the Low-Cycle Fatigue Properties of Commercially Pure Titanium", David Taylor Research Center Report No. DTRC/SME-88/77, Dec 1988

4. Rodabaugh, E.C. and Moore, S.E., "Phase Report No. 15-10 on Comparisons of Test Data with Code Methods for Fatigue Evaluation", Oak Ridge National Laboratory Report No. ORNL-TM-3520, Nov 1971

5. Markl, A.R.C., "Fatigue Tests of Piping Components", ASME Transactions 1952

6. Kaldor, L.M., "Analysis of Externally Pressurized Piping Systems, Phase One, Part A", DTNSRDC Report DTNSRDC/PAS-80/3 dated Mar 80

7. Submarine Safety (SUBSAFE) Design Review Procedure Manual (NOFORN), NAVSEA 0941- 041-3010 Change 7

8. Rodabaugh, E.C. and Moore, S.E., "Stress Indices for Girth Welded Joints, Including Radial Weld Shrinkage, Mismatch and Tapered-Wall Thickness", Oak Ridge National Laboratory Report No. ORNL/Sub-2913/9 (NUREG/CD-0371), Sep 1978

Appendix 1. Deflection of Alvin Variable Ballast Sphere

$OD := 23.78 \cdot in$

$t := .390 \cdot in$

$E := 15.5 \cdot 10^{6} \cdot psi \qquad \nu := .32$

$R := \frac{(OD - t)}{2} \qquad R = 11.695\, in$

$p := -4825 \cdot psi$

Radial Displacement - Roark 3rd Edition Table XIII Case No. 2

$s := p \cdot \frac{R}{2 \cdot t} \qquad s = -7.234 \times 10^{4}\, psi$

$d := R \cdot \frac{s}{E} \cdot (1 - \nu)$

$d = -0.037\, in$

Appendix 2. Beam Model of Lower Sphere Mounting Brackets

```
--------------------------------------------------------------------------------
SPR_FR     LOWER SPHERE FRAME                          REBIS
01/25/2002                                             AutoPIPE+6.00 MODEL  PAGE   1
--------------------------------------------------------------------------------
```

```
      *                             *******   **  *******   *******
     ***               **           **    **  **  **    **  **
    ** **            ******         **    **  **  **    **  **
   **   **    **   **  **   *****   *******   **  *******   *****
  *********   **   **  **  **   **  **        **  **        **
 **       **  **   **  **  **   **  **        **  **        **
**         **  *****   **   *****   **        **  **        *******
```

Pipe Stress Analysis and Design Program

Version: 6.00.16

Edition: Plus-Win

Developed and Maintained by

REBIS Industrial Workgroup Software
1600 Riviera Ave., Suite 300
Walnut Creek, CA 94596

```
************************************************************
**                                                        **
**              AUTOPIPE SYSTEM DATA LISTING              **
**                                                        **
************************************************************
```

SYSTEM NAME : SPR_FR

PROJECT ID : LOWER SPHERE FRAME

PREPARED BY : ______________________________
G. MAYERS

CHECKED BY : ______________________________

PIPING CODE	:	B31.1
VERTICAL AXIS	:	Y
AMBIENT TEMPERATURE	:	70.0 deg F
COMPONENT LIBRARY	:	AUTOPIPE
MATERIAL LIBRARY	:	AUTOB311
MODEL REVISION NUMBER	:	11

P O I N T D A T A L I S T I N G

POINT NAME	TYPE	OFFSETS (ft) X	Y	Z	DESCRIPTION
*** SEGMENT A					
A00	Run	0	0	0	PIPE ID = 1
A01	Run	-1.18	1.69	0	

Total weight of empty pipes : 0 lb

C O M P O N E N T D A T A L I S T I N G

POINT NAME	COORDINATE(ft) X	Y	Z	DATA TYPE	DESCRIPTION
*** SEGMENT A					
A00	0.00	0.00	0.00		
A01	-1.18	1.69	0.00		

Number of points in the system : 2

P I P E D A T A L I S T I N G

Pipe ID/ Material	Nom/ Sch	O.D. inch	Thickness(inch) W.Th.	Corr	Mill	Insu	Ling	Spec Grav	Weight(lb/ft) Pipe	Other	Total	ZL/ ZC
1	4	4.500	2.240	0	0.28	0	0	0	0	0	0	1.00
NS	NS											1.00

M A T E R I A L D A T A L I S T I N G

Material Name	Pipe ID	Density lb/cu.ft	Pois. Ratio	Temper. deg F	Modulus E6 psi Axial	Hoop	Shear	Expans. in/100ft
NS	1	0.0	0.30	70.0	3000.000	3000.000	1000.000	
				40.1	3000.000			-3.5880

M A T E R I A L A L L O W A B L E D A T A L I S T I N G

Material Name	Pipe ID	Temper. deg F	Allow. psi
NS	1	70.0	12500.0
		40.1	12500.0

FRAME POINT DATA LISTING

POINT NAME	COORDINATE(ft) X	Y	Z	DATA TYPE	DESCRIPTION
A00	0.00	0.00	0.00		
F01	0.00	0.00	1.15	ANCHOR	Rigid Thermal movements : None
F00	0.00	0.00	-1.02	ANCHOR	Translational stiffness lb/in X= FREE Y= FREE Z= RIGID Rotational stiffness ft-lb/deg X= RIGID Y= RIGID Z= FREE Thermal movements : None
A01	-1.18	1.69	0.00		
F02	-0.94	1.86	0.00	ANCHOR	Rigid Thermal movements : None

BEAM DATA LISTING
(Length - ft , Rigid End - ft)

BEAM ID		POINT NAME	LENGTH	SECTION ID/ MATERIAL ID	SECT TYPE	BETA ANGLE	RIGID END	RELEASE Ax	Y-Y	Z-Z
M1	From	A00	1.15	LWR	NS	125.00	0.00	N	N	N
	To	F01		TIL			0.00	N	N	N
M2	From	F00	1.02	LWR	NS	125.00	0.00	N	N	N
	To	A00		TIL			0.00	N	N	N
M3	From	A01	0.29	UPR	NS	0.00	0.00	N	N	N
	To	F02		SS			0.00	N	N	N

CROSS SECTION LISTING

Section ID/ Section Type	Area(sq.in) Axial	Y-Shear	Z-Shear	Inertia (in**4) Torsion	Y-Y Bend	Z-Z Bend
L2.5X2.5X3/16 L	0.90	0.31	0.31	0.0	0.6	0.6
L4X3X1/4 L	1.69	0.67	0.50	0.0	1.4	2.8
LWR NS	0.80	0.00	0.00	0.0	0.6	1.2
W6X9 W	2.68	1.00	1.13	0.0	2.2	16.4
UPR NS	1.00	0.00	0.00	0.0	1.3	0.0

BEAM MATERIAL LISTING

MATERIAL ID	Elastic modulus E6 psi	Poissons ratio	Yield Stress psi	Density lb/cu.ft	Expansion E-6 /F	Ultimate stress psi
A36	29.000	0.250	36000	490.00	6.50000	58000
TIL	15.500	0.320	40000	0.00	0.00000	50000
SS	28.300	0.300	40000	0.00	0.00000	50000

TEMPERATURE AND PRESSURE DATA

POINT NAME	CASE 1 PRESS. psi	CASE 1 TEMPER deg F	CASE 1 EXPAN. in/100ft	CASE 2 PRESS. psi	CASE 2 TEMPER deg F	CASE 2 EXPAN. in/100ft	CASE 3 PRESS. psi	CASE 3 TEMPER deg F	CASE 3 EXPAN. in/100ft
*** SEGMENT A									
A00	0	40.10	-3.588						
A01	0	40.10	-3.588						

H O T M O D U L U S (E6 psi)

POINT NAME	CASE 1	CASE 2	CASE 3
*** SEGMENT A			
A00	3000.000*		
A01	3000.000*		

* Non-standard material

H O T A L L O W A B L E S (psi)

POINT NAME	CASE 1 ALLOW	CASE 1 NOT USED	CASE 1 NOT USED	CASE 2 ALLOW	CASE 2 NOT USED	CASE 2 NOT USED	CASE 3 ALLOW	CASE 3 NOT USED	CASE 3 NOT USED
*** SEGMENT A									
A00	12500*								
A01	12500*								

< User-defined code allowable
* Non-code material

D I S P L A C E M E N T S

Point name	Load combination	TRANSLATIONS (in) X	Y	Z	ROTATIONS (deg) X	Y	Z
*** Segment A begin ***							
A00	T1	-0.032	0.050	0.000	0.001	0.001	0.004
A01	T1	0.008	-0.012	0.000	0.001	0.001	0.004
*** Segment A end ***							
A00	T1	-0.032	0.050	0.000	0.001	0.001	0.004
F01	T1	0.000	0.000	0.000	0.000	0.000	0.000
F00	T1	-0.033	0.050	0.000	0.000	0.000	0.004
A01	T1	0.008	-0.012	0.000	0.001	0.001	0.004
F02	T1	0.000	0.000	0.000	0.000	0.000	0.000

R E S T R A I N T R E A C T I O N S

Point name	Load combination	FORCES (lb) X	Y	Z	Result	MOMENTS (ft-lb) X	Y	Z	Result
F01	Anchor								
	T1	-1199	2001	-305	2353	1151	690	0	1342
F00	Anchor								
	T1	0	0	-342	342	1	1	0	1
F02	Anchor								
	T1	1199	-2001	647	2421	-55	78	343	356

G L O B A L F O R C E S & M O M E N T S

Point name	Load combination	FORCES (lb) X	Y	Z	Result	MOMENTS (ft-lb) X	Y	Z	Result
*** Segment A begin ***									
A00	T1	1199	-2001	647	2421	1149	689	0	1339
A01	T1	1199	-2001	647	2421	55	-77	-341	354
*** Segment A end ***									

Appendix 3. Lower Variable Ballast Piping for Alvin on Even Keel

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-------------------------------------------------------------------------------
VAB_LWR1   ALVIN LOWER VAB PIPING MTD SPHERE INPTS REBIS
01/24/2002                                        AutoPIPE+6.00 MODEL   PAGE    1
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      *                             *******   **  *******   *******
     ***               **           **   **   **  **   **   **
    ** **            ******         **   **   **  **   **   **
   **   **    **   **  **   *****   *******   **  *******   *****
  *********   **   **  **  **   **  **        **  **        **
 **       **  **   **  **  **   **  **        **  **        **
**         **  *****   **   *****   **        **  **        *******
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Pipe Stress Analysis and Design Program

Version: 6.00.16

Edition: Plus-Win

Developed and Maintained by

REBIS Industrial Workgroup Software
1600 Riviera Ave., Suite 300
Walnut Creek, CA 94596

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************************************************************
**                                                        **
**              AUTOPIPE SYSTEM DATA LISTING              **
**                                                        **
************************************************************
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SYSTEM NAME : VAB_LWR1

PROJECT ID : ALVIN LOWER VAB PIPING MTD SPHERE INPTS

PREPARED BY : ______________________
G. MAYERS

CHECKED BY : ______________________

PIPING CODE	:	B31.1
VERTICAL AXIS	:	Y
AMBIENT TEMPERATURE	:	70.0 deg F
COMPONENT LIBRARY	:	AUTOPIPE
MATERIAL LIBRARY	:	AUTOB311
MODEL REVISION NUMBER	:	9

P O I N T   D A T A   L I S T I N G

POINT NAME	TYPE	OFFSETS (ft-in) X	Y	Z	DESCRIPTION
*** SEGMENT A					
A09	Run	-1.26"	1.80"	-1.42"	PIPE ID = FTG
A08	Run	1.26"	-1.80"	0.00"	
A00	Run	0.00"	0.00"	1.42"	PIPE ID = TI
A01	Bend	0.00"	0.00"	2.99"	Elbow, Radius = 2.00 inch Bend angle change = 90.00 deg Mid point at 50.00 percent SIF = 1.00 Flex = 1.000
A02	Bend	-5.75"	0.00"	0.00"	Elbow, Radius = 2.00 inch Bend angle change = 90.10 deg Mid point at 50.00 percent SIF = 1.00 Flex = 1.000
A03	Bend	0.00"	0.00"	6.00"	Elbow, Radius = 2.00 inch Bend angle change = 90.10 deg Mid point at 50.00 percent SIF = 1.00 Flex = 1.000
A04	Valv	-4.72"	0.00"	0.00"	NS , Rating = Non-standard Weight = 0 lb Surface factor = 1.00 Non-standard joint, SIF = 1.00
A05	Run	-4.00"	0.00"	0.00"	
A06	Bend	-7.36"	0.00"	0.00"	Elbow, Radius = 2.00 inch Bend angle change = 90.00 deg Mid point at 50.00 percent SIF = 1.00 Flex = 1.000
A07	Run	0.00"	3.99"	0.00"	

Total weight of empty pipes : 0 lb

COMPONENT DATA LISTING

POINT NAME	X	Y	Z	DATA TYPE	DESCRIPTION
*** SEGMENT A					
A09	-1.26"	1.80"	-1.42"	ANCHOR	Rigid Thermal movements : T1
A08	0.00"	0.00"	-1.42"		
A00	0.00"	0.00"	0.00"		
A01 N	0.00"	0.00"	0.99"		
A01	0.00"	0.00"	2.99"	TI	
A01 M	-0.59"	0.00"	2.40"		
A01 F	-2.00"	0.00"	2.99"		
A02 N	-3.75"	0.00"	2.99"		
A02	-5.75"	0.00"	2.99"	TI	
A02 M	-5.16"	0.00"	3.58"		
A02 F	-5.75"	0.00"	4.99"		
A03 N	-5.74"	0.00"	6.99"		
A03	-5.74"	0.00"	8.99"	TI	
A03 M	-6.33"	0.00"	8.40"		
A03 F	-7.74"	0.00"	8.99"		
A04	-10.46"	0.00"	8.99"		
A05	-1'2.46"	0.00"	8.99"		
A06 N	-1'7.82"	0.00"	8.99"		
A06	-1'9.82"	0.00"	8.99"	TI	
A06 M	-1'9.23"	0.59"	8.99"		
A06 F	-1'9.82"	2.00"	8.99"		
A07	-1'9.82"	3.99"	8.99"	ANCHOR	Rigid Thermal movements : None

Number of points in the system : 22

P I P E   D A T A   L I S T I N G

Pipe ID/ Material	Nom/ Sch	O.D. inch	-----Thickness(inch)----- W.Th.	Corr	Mill	Insu	Ling	Spec Grav	Weight(lb/ft) Pipe	Other	Total	ZL/ ZC
TI NS	NS	0.500	0.065	0	0.01	0	0	1.03	0.17	0	0.22	1.00 1.00
FTG NS	NS	0.875	0.374	0	0.05	0	0	0	0	0	0	1.00 1.00

M A T E R I A L   D A T A   L I S T I N G

Material Name	Pipe ID	Density lb/cu.ft	Pois. Ratio	Temper. deg F	Modulus E6 psi Axial	Hoop	Shear	Expans. in/100ft
NS	FTG	0.0	0.30	70.027900.00027900.00010730.770				
NS	TI	282.0	0.32	70.0	15.500	15.500	5.870	

M A T E R I A L   A L L O W A B L E   D A T A   L I S T I N G

Material Name	Pipe ID	Temper. deg F	Allow. psi
NS	FTG	70.0 70.0	12500.0 16700.0
NS	TI	70.0 70.0	16700.0 16700.0

TEMPERATURE AND PRESSURE DATA

POINT NAME	-----C A S E 1------ PRESS. psi	TEMPER deg F	EXPAN. in/100ft	-----C A S E 2------ PRESS. psi	TEMPER deg F	EXPAN. in/100ft	-----C A S E 3------ PRESS. psi	TEMPER deg F	EXPAN. in/100ft
*** SEGMENT A									
A09	0	70.00	0.000						
A07	0	70.00	0.000						

H O T M O D U L U S (E6 psi)

POINT NAME	CASE 1	CASE 2	CASE 3
*** SEGMENT A			
A09	27900.000*		
A00	0*		
A07	0*		

* Non-standard material

H O T A L L O W A B L E S (psi)

POINT NAME	CASE 1 ALLOW	CASE 1 NOT USED	CASE 1 NOT USED	CASE 2 ALLOW	CASE 2 NOT USED	CASE 2 NOT USED	CASE 3 ALLOW	CASE 3 NOT USED	CASE 3 NOT USED
*** SEGMENT A									
A09	16700*								
A07	16700*								

< User-defined code allowable
* Non-code material

THERMAL ANCHOR MOVEMENTS AND DISPLACEMENTS

POINT NAME	LOAD CASE	DX (in)	DY (in)	DZ (in)	RX (deg)	RY (deg)	RZ (deg)
A09	Thermal 1	-0.03	0.05	0.00	0.017	0.007	0.003

D I S P L A C E M E N T S

Point name	Load combination	TRANSLATIONS (in) X	Y	Z	ROTATIONS (deg) X	Y	Z
*** Segment A begin ***							
A09	GR	0.000	0.000	0.000	0.000	0.000	0.000
	T1	-0.032	0.050	0.000	0.017	0.007	0.003
A08	GR	0.000	0.000	0.000	0.000	0.000	0.000
	T1	-0.032	0.050	-0.001	0.017	0.007	0.003
A00	GR	0.000	0.000	0.000	0.000	0.000	0.000
	T1	-0.032	0.049	-0.001	0.017	0.007	0.003
A01 N	GR	0.000	0.000	0.000	0.003	-0.001	0.002
	T1	-0.031	0.049	-0.001	0.030	0.064	0.027
A01 M	GR	0.000	0.000	0.000	0.005	-0.001	0.005
	T1	-0.029	0.047	0.000	0.045	0.118	0.061
A01 F	GR	0.000	0.000	0.000	0.008	-0.001	0.006
	T1	-0.027	0.045	0.003	0.058	0.150	0.085
A02 N	GR	0.000	-0.001	0.000	0.010	-0.002	0.006
	T1	-0.027	0.042	0.009	0.075	0.196	0.105
A02 M	GR	0.000	-0.001	0.000	0.012	-0.002	0.005
	T1	-0.025	0.039	0.014	0.088	0.245	0.116
A02 F	GR	0.000	-0.001	0.000	0.014	-0.002	0.003
	T1	-0.018	0.035	0.017	0.094	0.272	0.125
A03 N	GR	0.000	-0.002	0.000	0.014	-0.002	0.000
	T1	-0.009	0.032	0.017	0.095	0.241	0.137
A03 M	GR	0.000	-0.002	0.000	0.013	-0.002	-0.002
	T1	-0.004	0.028	0.019	0.087	0.165	0.145
A03 F	GR	0.000	-0.002	0.000	0.012	-0.001	-0.004
	T1	-0.002	0.024	0.021	0.074	0.067	0.149
A04	GR	0.000	-0.002	0.000	0.009	0.000	-0.008
	T1	-0.002	0.017	0.021	0.048	-0.080	0.138
A05	GR	0.000	-0.001	0.000	0.009	0.000	-0.008
	T1	-0.002	0.007	0.015	0.047	-0.081	0.138
A06 N	GR	0.000	0.000	0.000	0.004	0.001	-0.009
	T1	-0.002	-0.001	0.005	-0.004	-0.117	0.013
A06 M	GR	0.000	0.000	0.000	0.003	0.001	-0.007
	T1	-0.002	0.000	0.002	-0.018	-0.094	-0.031

D I S P L A C E M E N T S

Point name	Load combination	TRANSLATIONS (in) X	Y	Z	ROTATIONS (deg) X	Y	Z
A06 F	GR	0.000	0.000	0.000	0.002	0.000	-0.004
	T1	-0.001	0.000	0.000	-0.021	-0.055	-0.047
A07	GR	0.000	0.000	0.000	0.000	0.000	0.000
	T1	0.000	0.000	0.000	0.000	0.000	0.000

*** Segment A end ***

R E S T R A I N T   R E A C T I O N S

Point name	Load combination	FORCES (lb) X	Y	Z	Result	MOMENTS (ft-lb) X	Y	Z	Result
A09	Anchor								
	GR	-0.094	-0.363	0.027	0.376	0.177	-0.043	0.026	0.184
	T1	11.296	-1.416	-3.422	11.888	1.394	4.946	2.437	5.687
A07	Anchor								
	GR	0.094	-0.409	-0.027	0.420	0.043	0.008	-0.081	0.092
	T1	-11.296	1.416	3.422	11.888	-0.790	-1.008	-2.072	2.436

G L O B A L   F O R C E S   &   M O M E N T S

Point	Load	FORCES (lb)				MOMENTS (ft-lb)			
name	combination	X	Y	Z	Result	X	Y	Z	Result
*** Segment A begin ***									
A09	GR	0.094	0.363	-0.027	0.376	-0.177	0.043	-0.026	0.184
	T1	-11.296	1.416	3.422	11.888	-1.394	-4.946	-2.437	5.687
A08	GR	0.094	0.363	-0.027	0.376	-0.181	0.040	-0.078	0.201
	T1	-11.296	1.416	3.422	11.888	-0.881	-4.586	-0.891	4.754
A00	GR	0.094	0.363	-0.027	0.376	-0.138	0.029	-0.078	0.161
	T1	-11.296	1.416	3.422	11.888	-0.713	-3.250	-0.891	3.444
A01 N	GR	0.094	0.345	-0.027	0.358	-0.108	0.021	-0.078	0.135
	T1	-11.296	1.416	3.422	11.888	-0.596	-2.318	-0.891	2.554
A01 M	GR	0.094	0.316	-0.027	0.331	-0.069	0.011	-0.062	0.094
	T1	-11.296	1.416	3.422	11.888	-0.429	-1.153	-0.822	1.480
A01 F	GR	0.094	0.287	-0.027	0.303	-0.055	0.010	-0.027	0.062
	T1	-11.296	1.416	3.422	11.888	-0.360	-1.005	-0.655	1.253
A02 N	GR	0.094	0.255	-0.027	0.273	-0.055	0.014	0.013	0.058
	T1	-11.296	1.416	3.422	11.888	-0.360	-1.503	-0.449	1.610
A02 M	GR	0.094	0.225	-0.027	0.246	-0.043	0.012	0.041	0.061
	T1	-11.296	1.416	3.422	11.888	-0.291	-1.354	-0.282	1.413
A02 F	GR	0.094	0.196	-0.027	0.219	-0.018	0.003	0.051	0.055
	T1	-11.296	1.416	3.422	11.888	-0.124	-0.188	-0.213	0.309
A03 N	GR	0.094	0.160	-0.027	0.187	0.011	-0.013	0.051	0.054
	T1	-11.296	1.416	3.422	11.888	0.112	1.690	-0.213	1.707
A03 M	GR	0.094	0.131	-0.027	0.163	0.029	-0.023	0.058	0.069
	T1	-11.296	1.416	3.422	11.888	0.279	2.856	-0.144	2.874
A03 F	GR	0.094	0.101	-0.027	0.141	0.034	-0.024	0.072	0.083
	T1	-11.296	1.416	3.422	11.888	0.348	3.005	0.023	3.026
A04	GR	0.094	0.051	-0.027	0.110	0.034	-0.018	0.089	0.097
	T1	-11.296	1.416	3.422	11.888	0.348	2.231	0.344	2.284
A05	GR	0.094	-0.215	-0.027	0.236	0.034	-0.009	0.062	0.071
	T1	-11.296	1.416	3.422	11.888	0.348	1.090	0.816	1.405
A06 N	GR	0.094	-0.314	-0.027	0.329	0.034	0.003	-0.056	0.066
	T1	-11.296	1.416	3.422	11.888	0.348	-0.438	1.448	1.553
A06 M	GR	0.094	-0.343	-0.027	0.356	0.036	0.006	-0.090	0.097
	T1	-11.296	1.416	3.422	11.888	0.181	-0.841	1.064	1.368

G L O B A L   F O R C E S   &   M O M E N T S

Point name	Load combination	FORCES (lb) X	Y	Z	Result	MOMENTS (ft-lb) X	Y	Z	Result
A06 F	GR	0.094	-0.372	-0.027	0.384	0.039	0.008	-0.096	0.104
	T1	-11.296	1.416	3.422	11.888	-0.222	-1.008	-0.198	1.051
A07	GR	0.094	-0.409	-0.027	0.420	0.043	0.008	-0.081	0.092
	T1	-11.296	1.416	3.422	11.888	-0.790	-1.008	-2.072	2.436

*** Segment A end ***

ASME B31.1 (1998) CODE COMPLIANCE

(Moments in ft-lb) (Stress in psi)

Point name	Load combination	Ma (Sus.)	Mb (Occ.)	Mc (Exp.)	S.I.F	Eq. no.	Load type	Code Stress	Code Allow.
*** Segment A begin ***									
A09	GR + Max P	0.184			1.00	(11)	SUST	33	12500
	Cold to T1			5.687	1.00	(13)	DISP	1038	19800
A08	GR + Max P	0.201			1.00	(11)	SUST	37	12500
	Cold to T1			4.754	1.00	(13)	DISP	868	19800
A00 -	GR + Max P	0.161			1.00	(11)	SUST	29	12500
	Cold to T1			3.444	1.00	(13)	DISP	629	19800
A00 +	GR + Max P	0.161			1.00	(11)	SUST	225	16700
	Cold to T1			3.444	1.00	(13)	DISP	4810	25050
A01 N-	GR + Max P	0.135			1.00	(11)	SUST	189	16700
	Cold to T1			2.554	1.00	(13)	DISP	3566	25050
A01 N+	GR + Max P	0.135			1.00	(11)	SUST	189	16700
	Cold to T1			2.554	1.00	(13)	DISP	3566	25050
A01 M	GR + Max P	0.094			1.00	(11)	SUST	131	16700
	Cold to T1			1.480	1.00	(13)	DISP	2067	25050
A01 F-	GR + Max P	0.062			1.00	(11)	SUST	86	16700
	Cold to T1			1.253	1.00	(13)	DISP	1749	25050
A01 F+	GR + Max P	0.062			1.00	(11)	SUST	86	16700
	Cold to T1			1.253	1.00	(13)	DISP	1749	25050
A02 N-	GR + Max P	0.058			1.00	(11)	SUST	80	16700
	Cold to T1			1.610	1.00	(13)	DISP	2248	25050
A02 N+	GR + Max P	0.058			1.00	(11)	SUST	80	16700
	Cold to T1			1.610	1.00	(13)	DISP	2248	25050
A02 M	GR + Max P	0.061			1.00	(11)	SUST	85	16700
	Cold to T1			1.413	1.00	(13)	DISP	1974	25050
A02 F-	GR + Max P	0.055			1.00	(11)	SUST	76	16700
	Cold to T1			0.309	1.00	(13)	DISP	432	25050
A02 F+	GR + Max P	0.055			1.00	(11)	SUST	76	16700
	Cold to T1			0.309	1.00	(13)	DISP	432	25050
A03 N-	GR + Max P	0.054			1.00	(11)	SUST	76	16700
	Cold to T1			1.707	1.00	(13)	DISP	2384	25050
A03 N+	GR + Max P	0.054			1.00	(11)	SUST	76	16700
	Cold to T1			1.707	1.00	(13)	DISP	2384	25050

ASME B31.1 (1998) CODE COMPLIANCE

Point name	Load combination	Ma (Sus.) (Moments in ft-lb)	Mb (Occ.)	Mc (Exp.)	S.I.F	Eq. no.	Load type (Stress in psi)	Code Stress	Code Allow.
A03 M	GR + Max P	0.069			1.00	(11)	SUST	96	16700
	Cold to T1			2.874	1.00	(13)	DISP	4013	25050
A03 F-	GR + Max P	0.083			1.00	(11)	SUST	116	16700
	Cold to T1			3.026	1.00	(13)	DISP	4226	25050
A03 F+	GR + Max P	0.083			1.00	(11)	SUST	116	16700
	Cold to T1			3.026	1.00	(13)	DISP	4226	25050
A04	GR + Max P	0.097			1.00	(11)	SUST	136	16700
	Cold to T1			2.284	1.00	(13)	DISP	3190	25050
A05	GR + Max P	0.071			1.00	(11)	SUST	100	16700
	Cold to T1			1.405	1.00	(13)	DISP	1963	25050
A06 N-	GR + Max P	0.066			1.00	(11)	SUST	92	16700
	Cold to T1			1.553	1.00	(13)	DISP	2169	25050
A06 N+	GR + Max P	0.066			1.00	(11)	SUST	92	16700
	Cold to T1			1.553	1.00	(13)	DISP	2169	25050
A06 M	GR + Max P	0.097			1.00	(11)	SUST	136	16700
	Cold to T1			1.368	1.00	(13)	DISP	1911	25050
A06 F-	GR + Max P	0.104			1.00	(11)	SUST	146	16700
	Cold to T1			1.051	1.00	(13)	DISP	1469	25050
A06 F+	GR + Max P	0.104			1.00	(11)	SUST	146	16700
	Cold to T1			1.051	1.00	(13)	DISP	1469	25050
A07	GR + Max P	0.092			1.00	(11)	SUST	129	16700
	Cold to T1			2.436	1.00	(13)	DISP	3402	25050

*** Segment A end ***

Appendix 4. Upper Variable Ballast Piping for Alvin on Even Keel

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VAB_UPA   FILLED UPPER VAB PIPING ON SURFACE       REBIS
01/25/2002                                         AutoPIPE+6.00 MODEL  PAGE   1
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      *                             *******   **  *******   *******
     ***               **           **    **  **  **    **  **
    **  **           ******         **    **  **  **    **  **
   **   **    **   **   **   *****  *******   **  *******   *****
  *********   **   **   **  **    ** **        **  **        **
 **       **  **   **   **  **    ** **        **  **        **
**         **  *****   **   *****   **        **  **        *******
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Pipe Stress Analysis and Design Program

Version: 6.00.16

Edition: Plus-Win

Developed and Maintained by

REBIS Industrial Workgroup Software
1600 Riviera Ave., Suite 300
Walnut Creek, CA 94596

AUTOPIPE SYSTEM DATA LISTING

SYSTEM NAME : VAB_UPA

PROJECT ID : FILLED UPPER VAB PIPING ON SURFACE

PREPARED BY : ______________________
G. MAYERS

CHECKED BY : ______________________

PIPING CODE	:	B31.1
VERTICAL AXIS	:	Y
AMBIENT TEMPERATURE	:	70.0 deg F
COMPONENT LIBRARY	:	AUTOPIPE
MATERIAL LIBRARY	:	AUTOB311
MODEL REVISION NUMBER	:	27

P O I N T   D A T A   L I S T I N G

POINT NAME	TYPE	OFFSETS (ft) X	Y	Z	DESCRIPTION
*** SEGMENT A					
A00	Run	0	0	0	PIPE ID = TI
A01	Bend	0	0	0.41	Elbow, Radius = 2.00 inch Bend angle change = 45.18 deg Mid point at 50.00 percent SIF = 1.00 Flex = 1.000
A02	Run	0	-0.66	0.66	PIPE ID = FTG
A04	Run	-0.12	-0.08	0.08	PIPE ID = TI
A05	Bend	-2.27	0	0	Elbow, Radius = 2.00 inch Bend angle change = 90.00 deg SIF = 1.00 Flex = 1.000
A06	Bend	0	3.45	0	Elbow, Radius = 2.00 inch Bend angle change = 90.00 deg SIF = 1.00 Flex = 1.000
A08	Run	0	0	-0.26	PIPE ID = FTG
A09	Tee	-0.10	-0.06	-0.12	
A10	Run	0.10	0.06	-0.12	PIPE ID = TI
A11	Run	0	0	-2.41	PIPE ID = FTG
A12	Run	-0.10	-0.06	-0.11	PIPE ID = TI
A13	Bend	-0.16	-0.09	0	Elbow, Radius = 2.00 inch Bend angle change = 29.99 deg SIF = 1.00 Flex = 1.000
A14	Run	-0.53	0	0	
*** SEGMENT B					
A09	Tee	-2.48	2.65	0.77	PIPE ID = TI
B01	Bend	-0.16	-0.09	0	Elbow, Radius = 2.00 inch Bend angle change = 29.99 deg SIF = 1.00 Flex = 1.000
B02	Run	-0.53	0	0	

Total weight of empty pipes : 3 lb

C O M P O N E N T   D A T A   L I S T I N G

POINT NAME	------COORDINATE(ft)------ X	Y	Z	DATA TYPE	DESCRIPTION
*** SEGMENT A					
A00	0.00	0.00	0.00	ANCHOR	Rigid Thermal movements : T1
A01 N	0.00	0.00	0.34		
A01	0.00	0.00	0.41	TI	
A01 M	0.00	-0.01	0.41		
A01 F	0.00	-0.05	0.46		
A02	0.00	-0.66	1.07		
A04	-0.12	-0.74	1.15		
A05 N	-2.22	-0.74	1.15		
A05	-2.38	-0.74	1.15	TI	
A05 F	-2.38	-0.57	1.15		
A06 N	-2.38	2.54	1.15		
A06	-2.38	2.71	1.15	TI	
A06 F	-2.38	2.71	0.98		
A08	-2.38	2.71	0.89		
A09	-2.48	2.65	0.77	TEE	Other SIF - In = 1.00, Out = 1.00
A10	-2.38	2.71	0.66		
A11	-2.38	2.71	-1.76		
A12	-2.48	2.65	-1.87		
A13 N	-2.61	2.58	-1.87		
A13	-2.65	2.56	-1.87	TI	
A13 F	-2.69	2.56	-1.87		
A14	-3.17	2.56	-1.87	ANCHOR	Rigid Thermal movements : None
*** SEGMENT B					
A09	-2.48	2.65	0.77	TEE	Other SIF - In = 1.00, Out = 1.00
B01 N	-2.61	2.58	0.77		
B01	-2.65	2.56	0.77	TI	
B01 F	-2.69	2.56	0.77		
B02	-3.17	2.56	0.77	ANCHOR	Rigid Thermal movements : None

Number of points in the system : 27

P I P E D A T A L I S T I N G

Pipe ID/ Material	Nom/ Sch	O.D. inch	Thickness (inch) W.Th.	Corr	Mill	Insu	Ling	Spec Grav	Weight (lb/ft) Pipe	Other	Total	ZL/ ZC
TI NS	NS	0.500	0.065	0	0.01	0	0	1.03	0.17	0	0.22	1.00 1.00
FTG NS	NS	1.000	0.315	0	0.04	0	0	1.03	1.33	0	1.38	1.00 1.00

M A T E R I A L D A T A L I S T I N G

Material Name	Pipe ID	Density lb/cu.ft	Pois. Ratio	Temper. deg F	Modulus E6 psi Axial	Hoop	Shear	Expans. in/100ft
NS	TI	282.0	0.32	70.0	15.500	15.500	5.870	
NS	FTG	282.0	0.32	70.0	155.000	155.000	58.700	

M A T E R I A L A L L O W A B L E D A T A L I S T I N G

Material Name	Pipe ID	Temper. deg F	Allow. psi
NS	TI	70.0 70.0	16700.0 16700.0
NS	FTG	70.0 70.0	16700.0 16700.0

TEMPERATURE AND PRESSURE DATA

POINT NAME	CASE 1 PRESS. psi	TEMPER deg F	EXPAN. in/100ft	CASE 2 PRESS. psi	TEMPER deg F	EXPAN. in/100ft	CASE 3 PRESS. psi	TEMPER deg F	EXPAN. in/100ft
*** SEGMENT A									
A00	0	70.00	0.000						
A14	0	70.00	0.000						
*** SEGMENT B									
A09	0	70.00	0.000						
B02	0	70.00	0.000						

HOT MODULUS (E6 psi)

POINT NAME	CASE 1	CASE 2	CASE 3
*** SEGMENT A			
A00	15.500*		
A02	155.000*		
A04	15.500*		
A08	155.000*		
A10	15.500*		
A14	15.500*		
*** SEGMENT B			
A09	155.000*		
B02	155.000*		

* Non-standard material

HOT ALLOWABLES (psi)

	CASE 1			CASE 2			CASE 3		
POINT NAME	ALLOW	NOT USED	NOT USED	ALLOW	NOT USED	NOT USED	ALLOW	NOT USED	NOT USED
*** SEGMENT A									
A00	16700*								
A14	16700*								
*** SEGMENT B									
A09	16700*								
B02	16700*								

< User-defined code allowable
* Non-code material

THERMAL ANCHOR MOVEMENTS AND DISPLACEMENTS

POINT NAME	LOAD CASE	DX (in)	DY (in)	DZ (in)	RX (deg)	RY (deg)	RZ (deg)
A00	Thermal 1	0.01	-0.01	0.00	0.001	0.001	0.004

D I S P L A C E M E N T S

Point name	Load combination	TRANSLATIONS (in) X	Y	Z	ROTATIONS (deg) X	Y	Z
*** Segment A begin ***							
A00	GR	0.000	0.000	0.000	0.000	0.000	0.000
	T1	0.008	-0.012	0.000	0.001	0.001	0.004
A01 N	GR	0.000	-0.002	0.000	0.043	-0.011	-0.001
	T1	0.008	-0.012	0.000	-0.003	-0.002	-0.004
A01 M	GR	-0.001	-0.002	0.000	0.049	-0.013	-0.001
	T1	0.008	-0.012	0.000	-0.004	-0.003	-0.006
A01 F	GR	-0.001	-0.003	-0.001	0.055	-0.014	-0.001
	T1	0.008	-0.012	0.000	-0.004	-0.003	-0.007
A02	GR	-0.003	-0.013	-0.010	0.084	-0.030	0.008
	T1	0.006	-0.011	0.001	-0.008	-0.003	-0.022
A04	GR	-0.004	-0.014	-0.012	0.084	-0.030	0.008
	T1	0.005	-0.010	0.001	-0.008	-0.003	-0.022
A05 N	GR	-0.004	-0.014	-0.026	0.051	-0.028	-0.006
	T1	0.005	0.000	0.000	-0.003	-0.002	-0.012
A05 F	GR	-0.004	-0.014	-0.025	0.047	-0.026	0.000
	T1	0.006	0.000	0.000	-0.002	-0.001	-0.007
A06 N	GR	0.001	-0.014	-0.001	0.035	0.001	-0.060
	T1	0.000	0.000	0.000	0.002	0.001	0.008
A06 F	GR	0.003	-0.012	0.000	0.032	0.004	-0.080
	T1	0.000	0.000	0.000	0.002	0.001	0.004
A08	GR	0.003	-0.012	0.000	0.027	0.004	-0.088
	T1	0.000	0.000	0.000	0.002	0.001	0.003
A09	GR	0.002	-0.009	0.000	0.027	0.004	-0.088
	T1	0.000	0.000	0.000	0.002	0.001	0.003
A10	GR	0.003	-0.010	0.000	0.027	0.004	-0.088
	T1	0.000	0.000	0.000	0.002	0.001	0.003
A11	GR	0.001	-0.005	0.000	0.015	0.001	-0.043
	T1	0.000	0.000	0.000	-0.001	0.000	0.001

D I S P L A C E M E N T S

Point name	Load combination	TRANSLATIONS (in) X	Y	Z	ROTATIONS (deg) X	Y	Z
A12	GR	0.001	-0.004	0.000	0.015	0.001	-0.043
	T1	0.000	0.000	0.000	-0.001	0.000	0.001
A13 N	GR	0.000	-0.003	0.000	0.012	0.000	-0.039
	T1	0.000	0.000	0.000	-0.001	0.000	0.001
A13 F	GR	0.000	-0.002	0.000	0.010	0.000	-0.036
	T1	0.000	0.000	0.000	-0.001	0.000	0.001
A14	GR	0.000	0.000	0.000	0.000	0.000	0.000
	T1	0.000	0.000	0.000	0.000	0.000	0.000
*** Segment A end ***							
*** Segment B begin ***							
A09	GR	0.002	-0.009	0.000	0.027	0.004	-0.088
	T1	0.000	0.000	0.000	0.002	0.001	0.003
B01 N	GR	0.000	-0.007	0.000	0.022	0.003	-0.090
	T1	0.000	0.000	0.000	0.001	0.001	0.001
B01 F	GR	0.000	-0.005	0.000	0.018	0.002	-0.086
	T1	0.000	0.000	0.000	0.001	0.000	0.001
B02	GR	0.000	0.000	0.000	0.000	0.000	0.000
	T1	0.000	0.000	0.000	0.000	0.000	0.000
*** Segment B end ***							

R E S T R A I N T   R E A C T I O N S

Point name	Load combination	FORCES (lb) X	Y	Z	Result	MOMENTS (ft-lb) X	Y	Z	Result
A00	Anchor								
	GR	-0.114	-0.733	-0.018	0.742	0.630	-0.148	-0.012	0.647
	T1	-0.040	0.056	0.001	0.069	-0.058	-0.041	-0.076	0.104
A14	Anchor								
	GR	0.004	-0.566	0.024	0.567	0.065	-0.008	-0.425	0.430
	T1	-0.004	0.005	-0.005	0.008	-0.003	0.001	0.007	0.008
B02	Anchor								
	GR	0.110	-2.037	-0.005	2.040	0.116	0.020	-1.203	1.209
	T1	0.043	-0.061	0.004	0.075	0.008	0.003	-0.008	0.011

G L O B A L F O R C E S & M O M E N T S

Point name	Load combination	FORCES (lb) X	Y	Z	Result	MOMENTS (ft-lb) X	Y	Z	Result
*** Segment A begin ***									
A00	GR	0.114	0.733	0.018	0.742	-0.630	0.148	0.012	0.647
	T1	0.040	-0.056	-0.001	0.069	0.058	0.041	0.076	0.104
A01 N	GR	0.114	0.657	0.018	0.667	-0.392	0.109	0.012	0.407
	T1	0.040	-0.056	-0.001	0.069	0.039	0.027	0.076	0.090
A01 M	GR	0.114	0.643	0.018	0.653	-0.350	0.102	0.010	0.365
	T1	0.040	-0.056	-0.001	0.069	0.035	0.025	0.076	0.087
A01 F	GR	0.114	0.628	0.018	0.639	-0.315	0.095	0.006	0.329
	T1	0.040	-0.056	-0.001	0.069	0.032	0.023	0.074	0.084
A02	GR	0.114	0.437	0.018	0.452	0.020	0.026	-0.064	0.072
	T1	0.040	-0.056	-0.001	0.069	-0.003	-0.002	0.050	0.050
A04	GR	0.114	0.215	0.018	0.244	0.048	0.015	-0.035	0.061
	T1	0.040	-0.056	-0.001	0.069	-0.007	-0.005	0.040	0.041
A05 N	GR	0.114	-0.252	0.018	0.277	0.048	-0.023	-0.074	0.091
	T1	0.040	-0.056	-0.001	0.069	-0.007	-0.002	-0.078	0.079
A05 F	GR	0.114	-0.310	0.018	0.330	0.045	-0.026	-0.100	0.113
	T1	0.040	-0.056	-0.001	0.069	-0.007	-0.002	-0.081	0.081
A06 N	GR	0.114	-1.001	0.018	1.008	-0.012	-0.026	0.254	0.256
	T1	0.040	-0.056	-0.001	0.069	-0.004	-0.002	0.043	0.043
A06 F	GR	0.114	-1.059	0.018	1.066	0.158	-0.007	0.273	0.315
	T1	0.040	-0.056	-0.001	0.069	0.006	0.005	0.050	0.050
A08	GR	0.114	-1.081	0.018	1.087	0.260	0.004	0.273	0.377
	T1	0.040	-0.056	-0.001	0.069	0.011	0.008	0.050	0.052
A09 -	GR	0.114	-1.304	0.018	1.309	0.399	0.015	0.148	0.425
	T1	0.040	-0.056	-0.001	0.069	0.018	0.013	0.042	0.047
A09 +	GR	0.004	0.575	0.024	0.575	0.282	-0.002	-0.012	0.283
	T1	-0.004	0.005	-0.005	0.008	0.011	0.007	0.003	0.013
A10	GR	0.004	0.351	0.024	0.352	0.228	0.001	-0.057	0.235
	T1	-0.004	0.005	-0.005	0.008	0.010	0.006	0.002	0.012

G L O B A L F O R C E S & M O M E N T S

Point name	Load combination	FORCES (lb) X	Y	Z	Result	MOMENTS (ft-lb) X	Y	Z	Result
A11	GR	0.004	-0.184	0.024	0.186	0.027	0.011	-0.057	0.064
	T1	-0.004	0.005	-0.005	0.008	-0.002	-0.003	0.002	0.004
A12	GR	0.004	-0.408	0.024	0.409	0.062	0.009	-0.087	0.108
	T1	-0.004	0.005	-0.005	0.008	-0.003	-0.003	0.003	0.005
A13 N	GR	0.004	-0.439	0.024	0.440	0.064	0.006	-0.139	0.153
	T1	-0.004	0.005	-0.005	0.008	-0.003	-0.002	0.004	0.005
A13 F	GR	0.004	-0.459	0.024	0.459	0.065	0.004	-0.177	0.188
	T1	-0.004	0.005	-0.005	0.008	-0.003	-0.002	0.004	0.006
A14	GR	0.004	-0.566	0.024	0.567	0.065	-0.008	-0.425	0.430
	T1	-0.004	0.005	-0.005	0.008	-0.003	0.001	0.007	0.008
*** Segment A end ***									
*** Segment B begin ***									
A09	GR	0.110	-1.879	-0.005	1.882	0.116	0.016	0.159	0.198
	T1	0.043	-0.061	0.004	0.075	0.007	0.006	0.039	0.040
B01 N	GR	0.110	-1.910	-0.005	1.913	0.116	0.017	-0.080	0.142
	T1	0.043	-0.061	0.004	0.075	0.007	0.005	0.028	0.030
B01 F	GR	0.110	-1.929	-0.005	1.933	0.116	0.018	-0.242	0.269
	T1	0.043	-0.061	0.004	0.075	0.008	0.005	0.022	0.024
B02	GR	0.110	-2.037	-0.005	2.040	0.116	0.020	-1.203	1.209
	T1	0.043	-0.061	0.004	0.075	0.008	0.003	-0.008	0.011
*** Segment B end ***									

ASME B31.1 (1998) CODE COMPLIANCE

(Moments in ft-lb) (Stress in psi)

Point name	Load combination	Ma (Sus.)	Mb (Occ.)	Mc (Exp.)	S.I.F	Eq. no.	Load type	Code Stress	Code Allow.
*** Segment A begin ***									
A00	GR + Max P	0.647			1.00	(11)	SUST	904	16700
	Cold to T1			0.104	1.00	(13)	DISP	146	25050
A01 N-	GR + Max P	0.407			1.00	(11)	SUST	568	16700
	Cold to T1			0.090	1.00	(13)	DISP	125	25050
A01 N+	GR + Max P	0.407			1.00	(11)	SUST	568	16700
	Cold to T1			0.090	1.00	(13)	DISP	125	25050
A01 M	GR + Max P	0.365			1.00	(11)	SUST	509	16700
	Cold to T1			0.087	1.00	(13)	DISP	122	25050
A01 F-	GR + Max P	0.329			1.00	(11)	SUST	460	16700
	Cold to T1			0.084	1.00	(13)	DISP	117	25050
A01 F+	GR + Max P	0.329			1.00	(11)	SUST	460	16700
	Cold to T1			0.084	1.00	(13)	DISP	117	25050
A02 -	GR + Max P	0.072			1.00	(11)	SUST	100	16700
	Cold to T1			0.050	1.00	(13)	DISP	70	25050
A02 +	GR + Max P	0.072			1.00	(11)	SUST	9	16700
	Cold to T1			0.050	1.00	(13)	DISP	6	25050
A04 -	GR + Max P	0.061			1.00	(11)	SUST	8	16700
	Cold to T1			0.041	1.00	(13)	DISP	5	25050
A04 +	GR + Max P	0.061			1.00	(11)	SUST	85	16700
	Cold to T1			0.041	1.00	(13)	DISP	57	25050
A05 N-	GR + Max P	0.091			1.00	(11)	SUST	127	16700
	Cold to T1			0.079	1.00	(13)	DISP	110	25050
A05 N+	GR + Max P	0.091			1.00	(11)	SUST	127	16700
	Cold to T1			0.079	1.00	(13)	DISP	110	25050
A05 F-	GR + Max P	0.113			1.00	(11)	SUST	158	16700
	Cold to T1			0.081	1.00	(13)	DISP	114	25050
A05 F+	GR + Max P	0.113			1.00	(11)	SUST	158	16700
	Cold to T1			0.081	1.00	(13)	DISP	114	25050

ASME B31.1 (1998) CODE COMPLIANCE

Point name	Load combination	Ma (Sus.)	Mb (Occ.)	Mc (Exp.)	S.I.F	Eq. no.	Load type	Code Stress	Code Allow.
		(Moments in ft-lb)					(Stress in psi)		
A06 N-	GR + Max P	0.256			1.00	(11)	SUST	357	16700
	Cold to T1			0.043	1.00	(13)	DISP	60	25050
A06 N+	GR + Max P	0.256			1.00	(11)	SUST	357	16700
	Cold to T1			0.043	1.00	(13)	DISP	60	25050
A06 F-	GR + Max P	0.315			1.00	(11)	SUST	440	16700
	Cold to T1			0.050	1.00	(13)	DISP	70	25050
A06 F+	GR + Max P	0.315			1.00	(11)	SUST	440	16700
	Cold to T1			0.050	1.00	(13)	DISP	70	25050
A08 -	GR + Max P	0.377			1.00	(11)	SUST	527	16700
	Cold to T1			0.052	1.00	(13)	DISP	72	25050
A08 +	GR + Max P	0.377			1.00	(11)	SUST	47	16700
	Cold to T1			0.052	1.00	(13)	DISP	6	25050
A09 -	GR + Max P	0.425			1.00	(11)	SUST	53	16700
	Cold to T1			0.047	1.00	(13)	DISP	6	25050
A09 +	GR + Max P	0.283			1.00	(11)	SUST	35	16700
	Cold to T1			0.013	1.00	(13)	DISP	2	25050
A10 -	GR + Max P	0.235			1.00	(11)	SUST	29	16700
	Cold to T1			0.012	1.00	(13)	DISP	2	25050
A10 +	GR + Max P	0.235			1.00	(11)	SUST	328	16700
	Cold to T1			0.012	1.00	(13)	DISP	17	25050
A11 -	GR + Max P	0.064			1.00	(11)	SUST	90	16700
	Cold to T1			0.004	1.00	(13)	DISP	6	25050
A11 +	GR + Max P	0.064			1.00	(11)	SUST	8	16700
	Cold to T1			0.004	1.00	(13)	DISP	1	25050
A12 -	GR + Max P	0.108			1.00	(11)	SUST	13	16700
	Cold to T1			0.005	1.00	(13)	DISP	1	25050
A12 +	GR + Max P	0.108			1.00	(11)	SUST	150	16700
	Cold to T1			0.005	1.00	(13)	DISP	7	25050
A13 N-	GR + Max P	0.153			1.00	(11)	SUST	214	16700
	Cold to T1			0.005	1.00	(13)	DISP	8	25050

ASME B31.1 (1998) CODE COMPLIANCE

Point name	Load combination	Ma (Sus.)	Mb (Occ.)	Mc (Exp.)	S.I.F	Eq. no.	Load type	Code Stress	Code Allow.
		(Moments in ft-lb)				(Stress in psi)			
A13 N+	GR + Max P	0.153			1.00	(11)	SUST	214	16700
	Cold to T1			0.005	1.00	(13)	DISP	8	25050
A13 F-	GR + Max P	0.188			1.00	(11)	SUST	263	16700
	Cold to T1			0.006	1.00	(13)	DISP	8	25050
A13 F+	GR + Max P	0.188			1.00	(11)	SUST	263	16700
	Cold to T1			0.006	1.00	(13)	DISP	8	25050
A14	GR + Max P	0.430			1.00	(11)	SUST	601	16700
	Cold to T1			0.008	1.00	(13)	DISP	11	25050
*** Segment A end ***									
*** Segment B begin ***									
A09	GR + Max P	0.198			1.00	(11)	SUST	276	16700
	Cold to T1			0.040	1.00	(13)	DISP	56	25050
B01 N-	GR + Max P	0.142			1.00	(11)	SUST	198	16700
	Cold to T1			0.030	1.00	(13)	DISP	41	25050
B01 N+	GR + Max P	0.142			1.00	(11)	SUST	198	16700
	Cold to T1			0.030	1.00	(13)	DISP	41	25050
B01 F-	GR + Max P	0.269			1.00	(11)	SUST	376	16700
	Cold to T1			0.024	1.00	(13)	DISP	33	25050
B01 F+	GR + Max P	0.269			1.00	(11)	SUST	376	16700
	Cold to T1			0.024	1.00	(13)	DISP	33	25050
B02	GR + Max P	1.209			1.00	(11)	SUST	1689	16700
	Cold to T1			0.011	1.00	(13)	DISP	15	25050
*** Segment B end ***									

Appendix 5. Maximum Primary Loads

Maximum Straight Pipe Primary Load

Upper Run Point B02

Load	Calculated Moments (ft-lb) X	Y	Z	Resultant Load
Weight Surfaced	0.116	0.02	-1.203	1.209
Surf Pth Up	0.131	0.015	-1.058	1.067
Surf Pth Dwn	0.07	0.02	-1.026	1.028
Surf Roll Pt	0.238	0.347	-1.136	**1.211 <--Maximum**
Surf Roll St	-0.038	-0.312	-0.948	0.999
Sub Wt + Bouy	0.072	0.013	-0.769	0.772
Sub Pitch Up	0.044	0.033	-0.484	0.488
Sub Pth Dwn	0.029	-0.007	-0.482	0.483
Sub Roll Pt	0.096	-0.121	-0.531	0.554
Sub Roll St	-0.012	0.096	-0.458	0.468

Maximum Bend Primary Load

Upper Run Point A01 N

Load	Calculated Moments (ft-lb) X	Y	Z	Resultant Load
Weight Surfaced	-0.392	0.109	0.012	0.407
Surf Pth Up	-0.414	0.411	0.216	0.622
Surf Pth Dwn	-0.265	-0.222	-0.196	0.397
Surf Roll Pt	-0.705	0.413	0.051	**0.819 <--Maximum**
Surf Roll St	0.027	-0.224	-0.031	0.228
Sub Wt + Bouy	-0.257	0.069	0.01	0.266
Sub Pitch Up	-0.272	0.057	0.102	0.296
Sub Pth Dwn	-0.169	-0.017	-0.083	0.189
Sub Roll Pt	-0.337	0.161	-0.06	0.378
Sub Roll St	-0.008	-0.068	-0.051	0.085

Appendix 6. Maximum Primary Plus Secondary Load Range

Maximum Straight Pipe Primary Plus Secondary Load Range

Lower Run Point A00

Load	Calculated Moments (ft-lb) X	Y	Z
Weight Surfaced	-0.138	0.029	-0.078
Sub Anchor Movements	-0.771	-3.408	-0.931
Surf Pth Up	-0.135	-0.019	-0.072
Surf Pth Dwn	-0.098	0.055	-0.063
Surf Roll Pt	-0.125	-0.003	-0.079
Surf Roll St	-0.120	0.007	-0.083
Sub Wt + Bouy	-0.099	0.022	-0.056
Sub Pitch Up	-0.097	-0.014	-0.051
Sub Pth Dwn	-0.069	0.042	-0.045
Sub Roll Pt	-0.090	-0.001	-0.057
Sub Roll St	-0.085	0.006	-0.058

Load Combinations	Sum of Moments (ft-lb) X	Y	Z	Resultant Load Range	
Submergence	-0.732	-3.415	-0.909	3.609	
Surf Pitch Down to Sub Rise	-0.770	-3.477	-0.919	**3.678**	**<--Maximum**
Surf Pitch Down to Sub Dive	-0.742	-3.421	-0.913	3.618	
Surf Pitch Down to Sub Roll Port	-0.763	-3.464	-0.925	3.666	
Surf Pitch Down to Sub Roll Stbd	-0.758	-3.457	-0.926	3.658	
Surf Pitch Up to Sub Rise	-0.733	-3.403	-0.910	3.598	
Surf Pitch Up to Sub Dive	-0.705	-3.347	-0.904	3.538	
Surf Pitch Up to Sub Roll Port	-0.726	-3.390	-0.916	3.586	
Surf Pitch Up to Sub Roll Stbd	-0.721	-3.383	-0.917	3.578	
Surf Roll Port to Roll Stbd	0.005	0.010	-0.004	0.012	
Surf Pitch Up to Surf Pitch Dwn	0.028	0.056	0.006	0.063	
Surf Roll Stbd to Sub Roll Port	-0.741	-3.416	-0.905	3.611	
Surf Roll Stbd to Sub Roll Stbd	-0.736	-3.409	-0.906	3.603	
Surf Roll Stbd to Sub Rise	-0.748	-3.429	-0.899	3.623	
Surf Roll Stbd to Sub Dive	-0.720	-3.373	-0.893	3.563	
Surf Roll Port to Sub Roll Port	-0.736	-3.406	-0.909	3.601	
Surf Roll Port to Sub Roll Stbd	-0.731	-3.399	-0.910	3.594	
Surf Roll Port to Sub Rise	-0.743	-3.419	-0.903	3.613	
Surf Roll Port to Sub Dive	-0.715	-3.363	-0.897	3.553	
Sub Roll Port to Roll Stbd	0.005	0.007	-0.001	0.009	
Sub Rise to Dive	0.028	0.056	0.006	0.063	

Maximum Bend Primary Plus Secondary Load Range

Lower Run Point A03 F

Load	Calculated Moments (ft-lb) X	Y	Z
Weight Surfaced	0.034	-0.024	0.072
Sub Anchor Movements	0.338	3.113	0.024
Surf Pth Up	0.042	-0.009	0.066
Surf Pth Dwn	0.018	-0.025	0.059
Surf Roll Pt	0.029	0.019	0.063
Surf Roll St	0.036	-0.005	0.076
Sub Wt + Bouy	0.026	-0.019	0.053
Sub Pitch Up	0.032	-0.008	0.049
Sub Pth Dwn	0.013	-0.019	0.044
Sub Roll Pt	0.022	0.014	0.047
Sub Roll St	0.027	-0.004	0.056

Load Combinations	Sum of Moments (ft-lb) X	Y	Z	Resultant Load Range
Submergence	0.330	3.118	0.005	3.135
Surf Pitch Down to Sub Rise	0.352	3.130	0.014	3.150
Surf Pitch Down to Sub Dive	0.333	3.119	0.009	3.137
Surf Pitch Down to Sub Roll Port	0.342	3.152	0.012	**3.171 <--Maximum**
Surf Pitch Down to Sub Roll Stbd	0.347	3.134	0.021	3.153
Surf Pitch Up to Sub Rise	0.328	3.114	0.007	3.131
Surf Pitch Up to Sub Dive	0.309	3.103	0.002	3.118
Surf Pitch Up to Sub Roll Port	0.318	3.136	0.005	3.152
Surf Pitch Up to Sub Roll Stbd	0.323	3.118	0.014	3.135
Surf Roll Port to Roll Stbd	0.007	-0.024	0.013	0.028
Surf Pitch Up to Surf Pitch Dwn	-0.019	-0.011	-0.005	0.023
Surf Roll Stbd to Sub Roll Port	0.324	3.132	-0.005	3.149
Surf Roll Stbd to Sub Roll Stbd	0.329	3.114	0.004	3.131
Surf Roll Stbd to Sub Rise	0.334	3.110	-0.003	3.128
Surf Roll Stbd to Sub Dive	0.315	3.099	-0.008	3.115
Surf Roll Port to Sub Roll Port	0.331	3.108	0.008	3.126
Surf Roll Port to Sub Roll Stbd	0.336	3.090	0.017	3.108
Surf Roll Port to Sub Rise	0.341	3.086	0.010	3.105
Surf Roll Port to Sub Dive	0.322	3.075	0.005	3.092
Sub Roll Port to Roll Stbd	0.005	-0.018	0.009	0.021
Sub Rise to Dive	-0.019	-0.011	-0.005	0.023

Appendix 7. Stress Analysis of Alvin Variable Ballast Piping

Piping Physical Parameters

$Do := .500 \cdot in \quad t := .065 \cdot in \quad R := 2 \cdot in$

General Membrane Stress < Sm

Internal Pressure: $P := 2500 \cdot psi$

$Do\_max := 0.504 \cdot in \quad t\_min := .9 \cdot t \quad t\_min = 0.058in$ ASTM B338 Tolerances Included

$$ri := \frac{(Do\_max - 2 \cdot t\_min)}{2} \qquad ro := \frac{Do\_max}{2} \qquad rm := \frac{(Do\_max - t\_min)}{2}$$

$ri = 0.194in \qquad ro = 0.252in \qquad rm = 0.223in$

Straight pipe $\quad S2 := P \cdot \frac{\left(ro^2 + ri^2\right)}{ro^2 - ri^2} \qquad S2 = 9683psi \qquad Sm := 12500 \cdot psi$ OK

Bends $\quad S2 := P \cdot \frac{\left(ro^2 + ri^2\right)}{ro^2 - ri^2} \cdot \frac{(2 \cdot R - rm)}{(2 \cdot R - 2 \cdot rm)} \qquad S2 = 10274psi \qquad Sm := 12500 \cdot psi$ OK

Local Membrane Stress < 1.5 Sm

In the absence of discontunities local membrane stress equals general membrane stress.

Primary Membrane Stress plus Primary Bending Stress < 1.5 Sm

Evaluated in accordance with ASME B&PV Code Section III, NB-3652

$$B1 \cdot \frac{(P \cdot Do)}{2 \cdot t} + B2 \cdot \frac{Do}{2 \cdot I} \cdot Mi \le 1.5 \cdot Sm$$

Straight Tube Terminating at Fitting - Use Indices for as-welded butt weld.

$B1 := .5 \qquad B2 := 1.0$

Internal Pressure: $P := 2500 \cdot psi \qquad Mi := 14.5 \cdot in \cdot lbf$ At node B02 of upper run

$B1 \cdot \frac{(P \cdot Do)}{2 \cdot t} + B2 \cdot \frac{Do}{2 \cdot I} \cdot Mi = 6495psi \qquad Sm := 12500 \cdot psi \qquad 1.5 \cdot Sm = 18750psi$ OK

Bends

$B1 := -0.1 + 0.4 \cdot h$ $B1 = 0.999$ but not < 0 nor > 0.5, Therefore: $B1 := .5$

$B2 := \frac{1.30}{h^{\frac{2}{3}}}$ $B2 = 0.663$ but not < 1.0, Therefore: $B2 := 1.0$

where $h := t \cdot \frac{R}{rm^2}$

Internal Pressure: $P := 2500 psi$ $Mi := 9.8 \cdot in \cdot lbf$ At Node A01N of upper run

$B1 \cdot \frac{(P \cdot Do)}{2 \cdot t} + B2 \cdot \frac{Do}{2 \cdot I} \cdot Mi = 5948 psi$ $Sm := 12500 psi$ $1.5 \cdot Sm = 18750 psi$ OK

Primary Plus Secondary Stress < 3 Sm

Evaluated in accordance with ASME B&PV Code Section III, NB-3653.1

$$Sn = C1 \cdot \frac{(Po \cdot Do)}{2 \cdot t} + C2 \cdot \frac{Do}{2 \cdot I} \cdot Mi \le 3 \cdot Sm$$

Straight Tube Terminating at Fitting - Use Indices for as-welded butt weld.

$C1 := 1.0$

$C2 := 1.0 + \frac{0.094}{t}$ As noted in the body of report, Swagelok connections do not require a correction for weld crown or mismatch.

Therefore: $C2 := 1.0$

Pressure Range: $Po := 2500 psi + 4825 psi$ $Po = 7325 psi$

$Mi := 44.1 \cdot in \cdot lbf$ At node A00 of the lower run

$Sn = 33306 psi$ $3 \cdot Sm = 37500 psi$ OK

Bends

$C1 := \frac{(2 \cdot R - rm)}{2 \cdot (R - rm)}$ $C1 = 1.061$

$C2 := \frac{1.95}{h^{\frac{2}{3}}}$ but not < 1.5 $C2 = 0.994$ Therefore: $C2 := 1.5$

Pressure Range: $Po := 2500\,psi + 4825\,psi$ $Po = 7325psi$

$Mi := 38.0\,in \cdot lbf$ At Node A03F of lower run

$Sn = 36526psi$ $3 \cdot Sm = 37500psi$ <u>OK</u>

<u>Peak Stress</u>

Evaluated in accordance with ASME B&PV Code Section III, NB-3653.3

$$Sp := K1 \cdot C1 \cdot \frac{(Po \cdot Do)}{2 \cdot t} + K2 \cdot C2 \cdot \frac{Do}{2 \cdot I} \cdot Mi$$

<u>Straight Tube Terminating at Fitting</u> - Use Indices for as-welded butt weld.

$C1 := 1.0$ $C2 := 1.0$ As above

$K1 := 1.2$ $K2 := 1.8$

$Mi := 44.1 \cdot in \cdot lbf$ At node A00 of the lower run

$Sp = 43047psi$

$Salt := \frac{Sp}{2}$ $Salt = 21523psi$ Therefore: $N := 30000$

<u>Bends</u>

$C1 := 1.061$ $C2 := 1.5$ As above

$K1 := 1$ $K2 := 1$

$Mi := 38.0\,in \cdot lbf$ At Node A03F of lower run

$Sp = 36526psi$ Therefore: Straight pipe controls fatigue life

Appendix 8. External Pressure Analysis of Alvin Variable Ballast Piping

Piping Physical Parameters

$Do := .500 \cdot in$ $\quad\quad t := .065 \cdot in$

Evaluated in accordance with ASME B&PV Code Section III, NB-3133.3

$T := t \quad\quad \frac{Do}{T} = 7.692 \quad\quad \frac{L}{Do} > 50$

Per Section II Part D Figure G $\quad A = 0.019$

Per Section II Part D Figure NFT-2 $\quad B := 19300$

$$Pa1 := \left[\frac{2.167}{\left(\frac{Do}{T}\right)} - 0.0833\right] \cdot B \quad\quad Pa1 = 3829 psi$$

S is lesser of 1.5 Sm or 0.9 Sy

$Sm := 12500 psi$ and $Sy := 25000 psi$

Lesser of $1.5 \cdot Sm = 18750 psi$ or $.9 \cdot Sy = 22500 psi$ Therefore: $S := 18750 psi$

$$Pa2 := 2 \cdot \frac{S}{\frac{Do}{T}} \cdot \left(1 - \frac{1}{\frac{Do}{T}}\right) \quad\quad Pa2 = 4241 psi$$

Therefore, the maximum allowable external pressure is 3829 psi..

Evaluated in accordance with DTNSRDC Report DTNSRDC/PAS-80/3

Ref: Kaldor, L.M., "Analysis of Externally Pressurized Piping Systems, Phase One, Part A", DTNSRDC Report DTNSRDC/PAS-80/3 dated Mar 80

$L := 100 \cdot in \qquad E := 15.5 \cdot 10^{6} \cdot psi \qquad S := Sy$

$Dm := Do - T$

$Lcritical := 1.598 \cdot Dm \cdot \sqrt{\frac{Dm}{T}} \qquad Lcritical = 1.798in$

$Lstar := \min(L, Lcritical) \qquad Lstar = 1.798in$

$$a := \frac{Lstar}{T} \cdot \frac{S}{E} \cdot \sqrt{\frac{Dm}{T}}$$

$b := .276 \cdot a + .383$

$Pc := \frac{S}{b} \cdot \frac{T}{Dm} \qquad Pc = 9005psi$

In accordance with SUBSAFE Design Review Procedure Manual (3010) Pdesign is taken as Pdesign in the DTNSRDC report divided by 1.5.

$Pdesign := .85 \cdot \frac{Pc}{1.5} \qquad Pdesign = 5103psi$